Electromagnetic Compatibility of Mars Orbiter Mission Spacecraft

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Abstract — The MARS Orbiter Mission (MOM) spacecraft carries on-board sensitive receiver and high gain antenna system to cater to the requirement of inter-planetary and deep space communication. This paper describes, among others, the stringent EMC requirements for MOM spacecraft, summary of EMC analysis carried out, modification on subsystem level EMI/EMC test limit and EMI/ESD mitigation techniques followed to achieve EMC compliance of MOM Spacecraft.

Index Terms — Mars Orbiter Mission Spacecraft, EMI/EMC/ESD.

I. INTRODUCTION

The MARS Orbiter Mission (MOM) spacecraft carries on-board sensitive receiver having sensitivity of -135 dBm and with high gain antenna system (250W) to cater to the requirement of inter-planetary and deep space communication. There are four TTC antennas mounted at different locations onboard the spacecraft (two Low Gain Antenna (LGA), one on +Yaw panel and another on –Yaw panel, Medium Gain Antenna (MGA) on extended top deck (+Roll side) and High Gain Antenna (HGA) on –Pitch side, with different antenna gain parameters and associated onboard losses [1]. The presence of sensitive receiver along with high power transmit antenna on the same platform makes it challenging to achieve compliance of intra system Electromagnetic Compatibility. This calls for stringent EMI/EMC requirements to be met both at subsystem and system levels. This paper briefly describes the details of analysis, testing and EMI/ESD mitigation techniques followed to achieve EMC Compliance of MOM Spacecraft.

II. EM ANALYSIS & EMC/ESD TEST LIMITS FOR MOM

For MOM spacecraft, the EMI/EMC/ESD test limits have been made more stringent (particularly in the frequency range of Receiver bandwidth) and modified accordingly, based on prior analysis carried out to predict:

- RF radiation level at different locations of the spacecraft,
- Surface / Internal (Deep dielectric) Charging levels on the exposed / interior surfaces of spacecraft

in (a) Earth Orbit, (b) Inter planetary region and (c) Mars Orbit. In the earth orbit, the spacecraft traverses Van-Allen belt several times, where high energy electrons and protons are trapped. NASA Analysis Charging Programme (NASCAP) has been used to predict the surface charging level in Earth Orbit environment and Space ENVironment Information System (SPENVIS) software used to predict the internal charging level. In Interplanetary region and Mars orbit region, low energy electrons (<100 keV) and higher energy protons (>1Mev) from solar energetic particle events are the sources of charging and spacecraft charging due to protons is more of a concern [2]. Surface charging due to low energy electrons and internal charging due to high energy proton fluency in interplanetary and Mars orbits have been predicted using SPENVIS.

A. E-Field Computation

To determine the magnitude of Electric-field at the subsystems in the Field of View (FOV) of MGA and HGA feeds, analysis/simulation was carried out using Computer Simulation Tool (CST) Microwave studio Software. Fig.1 shows the simulated model for HGA feed and Fig. 2 shows the computed of E-field distribution of HGA feed at different locations where packages are mounted. Similar analysis was carried out for all other subsystems in the FOV of LGA, MGA and HGA. The result was used to establish the Radiated Susceptibility Levels at the location of other packages, corresponding to the frequencies of these antennae. This in turn was useful in tailoring to more stringent levels of the EMI/EMC/ESD test limits both at subsystem and system levels for MOM spacecraft.

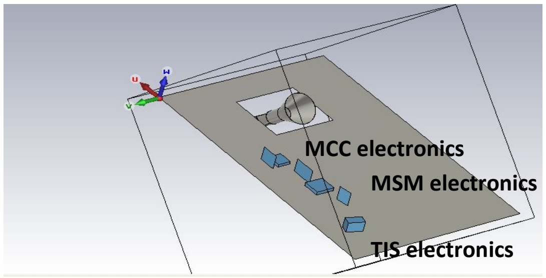

Fig.1: Simulated Model for High Gain Antenna Feed

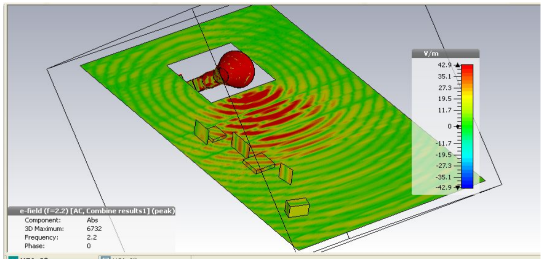

Fig. 2: Computation of E-field Distribution of High Gain Antenna Feed at packages locations

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B. Spacecraft surface and internal charging analysis

This was carried out for MOM spacecraft using NASCAP and SPENVIS and ESD Test Limits and ESD mitigation techniques were arrived at accordingly. Fig. 3 shows surface charging levels w.r.t altitude and latitude in earth orbit. Fig. 4 shows the surface details of MOM spacecraft, as modelled by NASCAP. The details of surface charge build up in eclipse condition for MOM spacecraft are shown in Fig. 5. Table-1 gives the details of absolute potential build up (as predicted by NASCAP) on MOM spacecraft surfaces in sunlit and eclipse conditions.

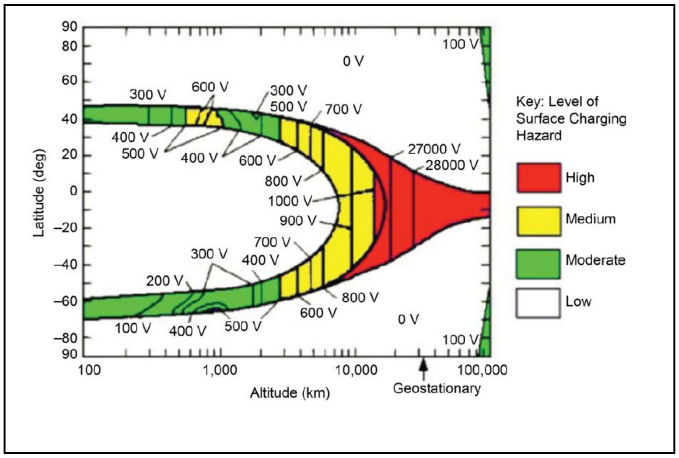

Fig. 3: Surface Charging Levels w.r.t. to Altitude and Latitude above earth

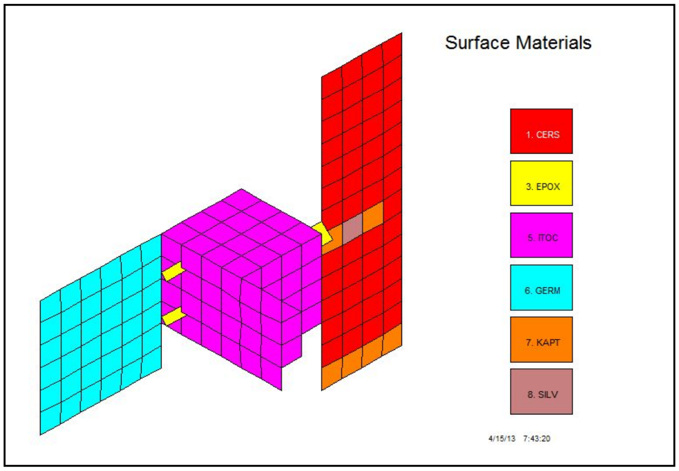

Fig. 4: MOM Spacecraft as modelled by NASCAP

The Radiated Emission and Susceptibility test limits for MOM spacecraft at subsystem level have been arrived at based on these prior theoretical calculations, software simulations / analysis. The results of the analyses carried out and the modifications made on EMI/EMC/ESD Test Limits applicable at Subsystem and System Level are given in detail in reference [3], Doc. No. ISRO-ISAC-MOM-TE-1889. The subsystem and system level EMC tests were carried out and qualified as per these modified levels.

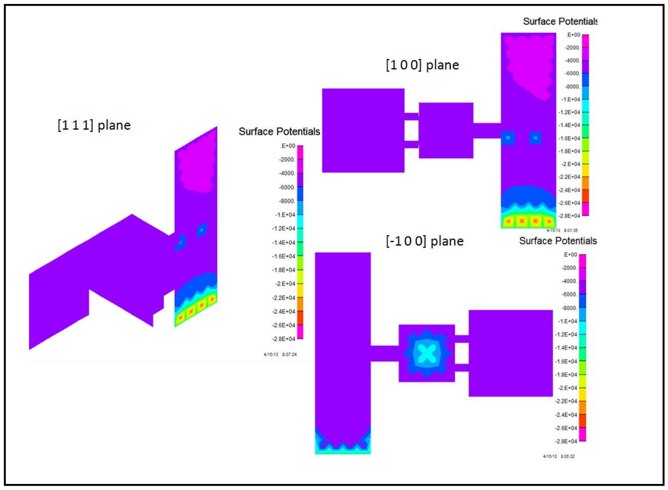

Fig. 5: MOM S/C: Prediction of Surface Potentials in the Eclipse condition

TABLE-1
ABSOLUTE POTENTIALS PREDICTION FOR MOM SPACECRAFT IN SUNLIT AND ECLIPSE CONDITIONS

Material	Sunlit (in KV)	Eclipse (in KV)
ITOC	-1.043	-5.269
GERM	-1.043	-5.269
KAPTON	-20.55	-24.51
KAPTON-MID	-1.277	-8.649
CERS	-5.103	-8.202
SILV	-1.044	-5.27
CFRP	-1.044	-5.27
EPOX	-1.044	-5.32
CERM	-7.29	-10.89

C. EMI/EMC/ESD Test Limits for MOM Spacecraft

Following are the highlights of the changes made in EMI/EMC/ESD Test Limits for MOM S/C.

- Radiated Emissions limit for subsystem level testing has been calculated based on the Receiver Sensitivity and has been computed as 5dBμV/m at 1890-2334MHz (nominally 60dBμV/m)
- Radiated Susceptibility levels have been determined as 20 V/m in the transmitter frequency range 2290-2300 MHz. (nominally 5 V/m in freq. Range 30 MHz – 10 GHz)
- Charging analysis has been carried out for the earth-centric, heliocentric and mars centric phases. Based on this analysis the ESD Levels have been estimated to be 14 KV for the Radiated ESD test and 10 KV for the Single point discharge and structural current test. (nominally 7KV and 5 KV respectively).

- Based on the charging analysis of the MOM Spacecraft, the following were implemented from the ESD perspective:
    - All subsystem harness present outside has been covered with Copper tape.
    - The propellant tank cut out area on the –Pitch panel has been covered with ESD (Bronze) mesh
    - Star Sensors Electronics have been covered with ESD Mesh. (The mesh provides an additional RF shielding of 20 dB in the freq range 1GHz- 40 GHz)
- Based on the Microwave Simulation in CST Software, it was analyzed that (Course Analog Sun Sensor) CASS -42 and CASS - 47 Subsystem would be experiencing high Electric Field (about 80 V/m) due to the proximity of the MGA, hence they were relocated.

III. SUBSYSTEM LEVEL EMI/EMC TESTING

All subsystems have been tested for the MOM Spacecraft specific EMI/EMC test levels, apart from the General EMI/EMC tests.

- Mitigation techniques have been implemented to some of the packages at subsystem level EMI/ EMC testing, that had emissions exceeding the specified limit and the improvement achieved has been recorded (Example: Star Sensors, refer Fig. 6, Cu tape implementation to reduce radiated emissions from the package). The same EMI mitigation techniques have been implemented at Satellite Level.
- E-Field at each antenna port i.e. LGA, MGA and HGA due to the emissions from each subsystem has been computed by considering the distance, placement of the package. Based on these calculations the initial non-compliant subsystems (such as TMTC, AOCE, DDOR, MDH etc.) have been identified. For these subsystems, mitigation techniques were carried during disassembled mode IST as per the EMI/EMC test committee recommendations.

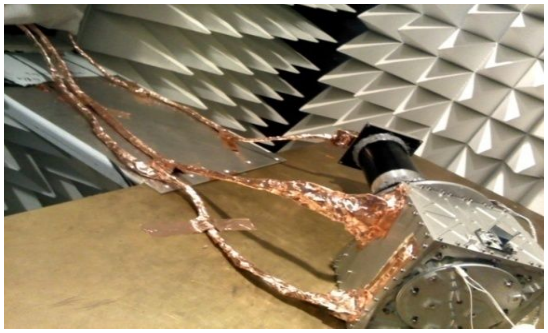

Fig. 6: Star Sensor with all the connectors and harness covered with Cu tape

IV. SPACECRAFT LEVEL MEASUREMENTS IN CLEAN ROOM

The measurements were carried out in ISAC Clean Room, both during disassembled mode IST (Integrated Spacecraft Testing) and assembled mode IST. Following are the highlights of the

A. Disassembled Mode Measurements

- The RF leakage points in the TMTC, AOCE, DDOR and MDH packages have been identified by Sniffing test. The RF leakage was arrested by wrapping the necessary areas with Copper tape. The improvement achieved in arresting RF leakage by additional shielding were measured and recorded. (Example: Refer Fig. 7, DDOR packages covered with Cu tape, provided 10 dB improvement).
- Cu tape wrapping was done for connectors / harness of TMTC, AOCE, DDOR, MDH packages.
- +Yaw panel and –Yaw panel LGA Receiver port measurements were carried out to ensure compliance from TMTC and DDOR subsystems respectively.

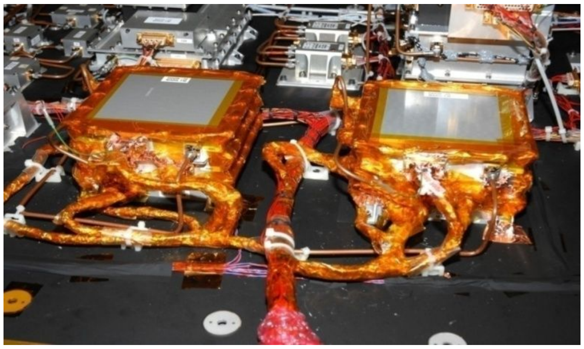

Fig. 7: DDOR subsystems covered with Cu tape

B. Assembled Mode Measurements

- Assembled IST antenna terminal measurements for LGA (+YAW and -YAW), MGA and HGA antennas were carried out at the Uplink Receive (UR) port of these antennae, to measure the level of E-field at the input of these antennae. This was done in the final assembled condition of the MOM spacecraft, when the spacecraft was powered ON in on-orbit configuration (Fig. 8). No spurious emissions were observed in the receiver bandwidth at all the antennae ports.
- The emissions observed at all these antenna ports were less than -141 dBm, indicating that the system noise has been brought down to less than -141 dBm and providing a noise margin of 6 dB for the Receiver operation. Fig. 9 shows the measured emissions at HGA port.
- Preliminary Launcher Compatibility Test: The emissions did not exceed the specified limits from (14 KHz – 18GHz) but the noise floor of the spectrum was slightly higher in the GPS Receiver bandwidth (1570–1580 MHz) as this test was performed in the clean room environment.

Hence, it was necessary to perform this test in the RF Shielded Anechoic Chamber at ISITE.

- Also, EMC auto compatibility and the polarity test for all the antennas were carried out in the RF shielded fully anechoic chamber at ISITE, as this provides an RF free environment.

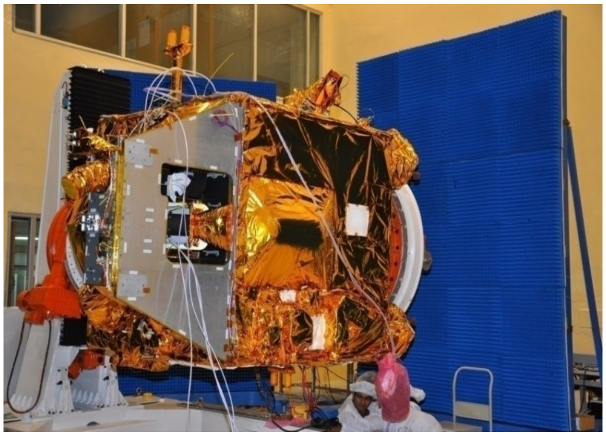

Fig. 8: Spacecraft in assembled condition

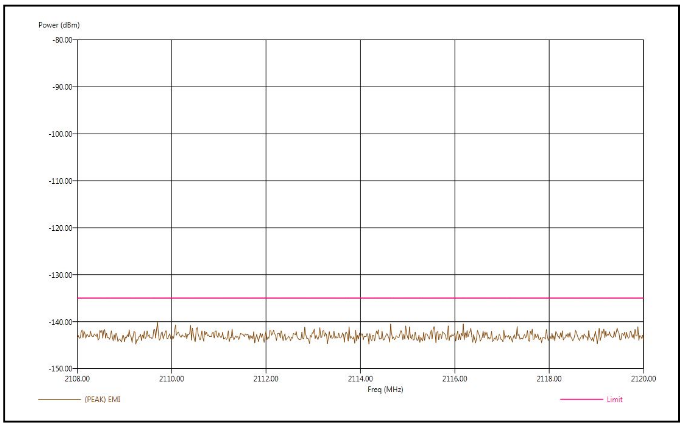

Fig.9: Measured Emissions at High Gain Antenna port, as less than -141 dBm

V. SYSTEM LEVEL EMC MEASUREMENTS IN ANECHOIC CHAMBER

The measurements were carried out in ISITE Anechoic Chamber. Following are the highlights of the measurements.

- The System Level EMC Test, S/C- Launcher RF compatibility tests, all antennae polarization tests and Auto-compatibility test were completed successfully with excellent results.
- The Command threshold for the receiver has been established at -132 dBm in the radiated mode in On-orbit configuration. This is as per the specification requirement for the Receiver.

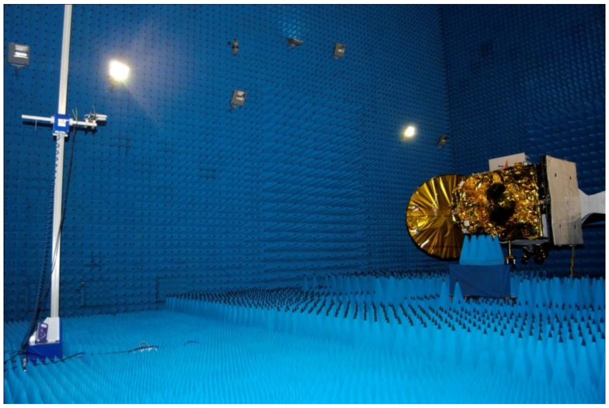

Fig. 10: MOM S/C undergoing System Level EMC and Antenna Polarization test in Anechoic Chamber

VI. CONCLUSION

- This paper briefly outlines the efforts taken by the EMI/EMC Test Committee towards achieving Electromagnetic Compatibility of Mars Orbiter Mission Spacecraft (MOM).
- A report [4] describing in details, among others, the stringent EMC requirements for MOM spacecraft, subsystem level EMI/EMC test results, different EMI/ESD mitigation techniques followed at system level during disassembled mode IST to achieve EMC compliance of the Mars Orbiter Mission (MOM) Spacecraft, System Level Test Results, covering EMC Test, S/C- Launcher RF compatibility tests, all antennae polarization tests and Auto-compatibility test has been prepared. The high lights of this report are described in this paper.
- The excellent on-orbit EMC performance of the Mars Orbiter Mission Spacecraft is the final testimony for all the analysis, testing and EMI/ESD mitigation techniques followed towards achieving EMC Compliance of the MOM spacecraft.

REFERENCES

[1] Mars Orbiter Mission Spacecraft Configuration, ISRO Internal Document, March-2013.
[2] Nelson W. Green and A. Robb Frederickson, “A Study of Spacecraft Charging due to Exposure to Interplanetary Protons”, JPL, California Institute of Technology, AIP Conf. Proceedings, 813, p. 694, 2006
[3] EMI / EMC / ESD test requirements and test procedure for Mars Orbiter Mission spacecraft, ISRO Internal Document, Doc. No. ISRO – ISAC – MOM – TE-1889. May-2013.
[4] EMI/EMC/ESD Test Results of MOM spacecraft, ISRO Internal Document, ISRO-ISAC-MOM-PR-2448, Sept-2014.